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Title: Radiative shocking and acceleration of polycrystalline slabs for investigation of ablative Rayleigh-Taylor instability triggered by ablator microstructure

Author(s): N.M. Hoffman, D.L. Tubbs, D.C. Swift, J.A. Cobble, G.A. Kyrala, T.E. Tierney

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Los Alamos
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Radiative shocking and acceleration of polycrystalline slabs for investigation of ablative Rayleigh-Taylor instability triggered by ablator microstructure

Nelson Hoffman, David Tubbs, Damian Swift,
James Cobble, George Kyrala, Thomas Tierney
Los Alamos National Laboratory

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NIF ignition capsules are the most unstable imploding systems ever devised by the national inertial fusion program.

Growth rate for ablative Rayleigh-Taylor instability is roughly*

$$\gamma = \sqrt{kg} - \beta k v_a$$

g = shell acceleration, k = perturbation wavenumber, $\beta \sim 2$,
v_a = velocity of ablation front

Number of unstable e-foldings for mode *m* during acceleration is

$\gamma t \approx \sqrt{m} - m/\alpha$ *where* m = mode number = kR_0; R_0 is initial capsule radius

$$\alpha = \frac{\text{shell compression factor x initial shell aspect ratio}}{\beta \text{ x fraction of shell ablated}} \sim \frac{4 \times 6.25}{2 \times 0.5} \sim 25$$

Maximum growth $(\gamma t)_{max} = \alpha/4 \sim 6.3$ occurs for mode $m_{max} = \alpha^2/4 \sim 150$
6.3 e-foldings implies growth factor ~ 540

Further growth during deceleration leads to total growth factor ~1000

*H. Takabe *et al., Phys. Fluids* **28**, 3676 (1985); R. Betti *et al., Phys. Plasmas* **3**, 2122 (1996); *Phys. Plasmas* **2**, 3844 (1995).

Therefore it is vital to identify and control all perturbation sources that could trigger ablative Rayleigh-Taylor instability

- **One obvious perturbation "seed" is surface roughness**
  - *Specification for allowable roughness of NIF ignition capsule* is based on computed perturbation growth, validated by experiments*

- **But what about *internal microstructure* of shell materials?**
  - *Beryllium shells are composed of individual crystalline grains with anisotropic elastic/plastic properties*
  - *Polymer shells are composed of long molecular chains that might "stack like logs" with a preferred orientation*

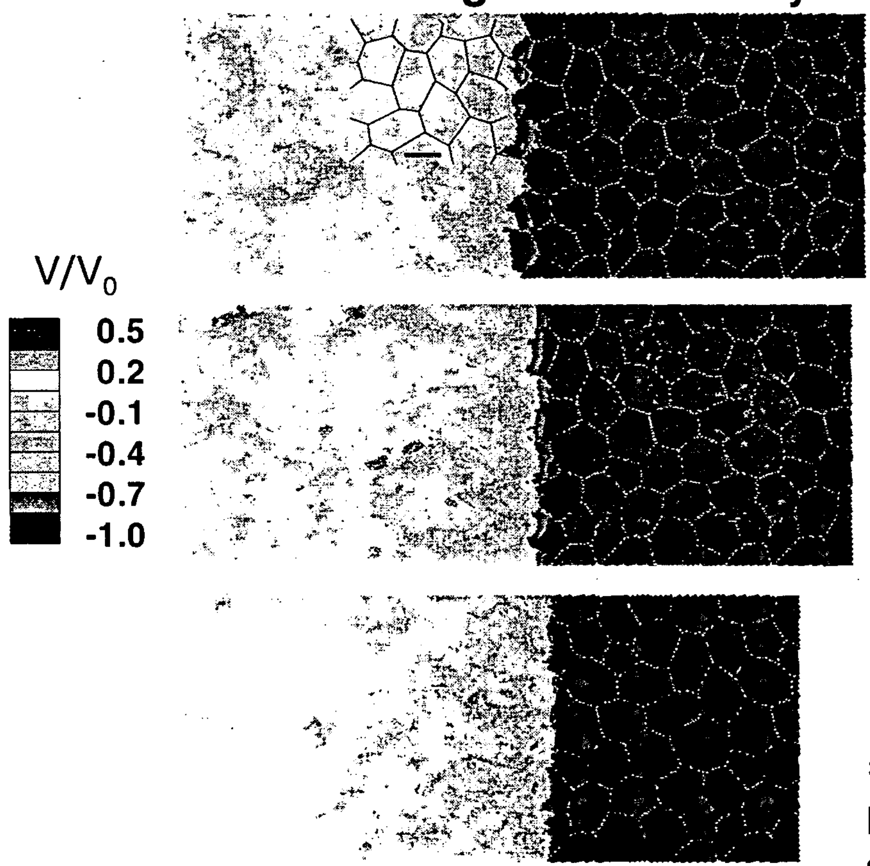
What happens when shock waves transit anisotropic material?
What happens when such material is accelerated by radiation drive?
We need a specification for allowable internal anisotropy.

*R.B. Stephens, S.W. Haan, D.C. Wilson, "Characterization Specifications for Baseline Indirect Drive NIF Targets", internal General Atomics memo

Recent advances allow computation of fluctuating velocity field behind shock wave in anisotropic material*. This is likely to seed ablative Rayleigh-Taylor instability.

Normalized longitudinal velocity fields

Longitudinal Velocity Fluctuations in Shock Compression of Polycrystalline α-Iron*



V_0 = 150 m/s P_s = 5.5 GPa

— 10 μm

V_0 = 300 m/s P_s = 12 GPa

V_0 = 1000 m/s P_s = 45 GPa

***Y. Horie and K. Yano, "Particle Velocity Fluctuations in the Shock Compression of Solids", LA-13936-MS, May 2002**

How should we go about developing a specification for ablator microstructure?

- **Theoretical/computational approach**
  - *Develop models, simulate relevant processes numerically*
    - *For example, add radiation to Horie-Yano code, develop 3D Be grain model*
  - *This was approach used in developing surface-roughness spec*
  - *Experiments are still necessary to validate models and simulations*

- **Empirical approach**
  - *Observe behavior of Be/Cu slabs on Omega, Z, early NIF,...*
  - *Relate behavior (via computed single-mode growth factors) to* ***equivalent surface perturbation***
  - *Since surface-roughness spec already exists, we thereby reduce microstructure spec to a previously solved problem*
  - *Computation is still necessary to determine growth factors, and make diagnostic predictions*

Either approach must wait for full NIF for final confirmation. Similar experiments must be done in either approach.

We are proceeding with the empirical approach.

- **Face-on radiography* of accelerated Be/Cu foils shows growth of unstable perturbations**
  - *Data consists of time-varying spatial distribution of slab areal density* $\int \rho\, dz$
  - *Fourier analysis of areal density distribution gives power spectrum* $S(k,t)$
  - *Computation gives time-dependent linear growth factor spectrum* $f(k,t)$
  - *Then "equivalent initial surface perturbation" is*

$$P_{eq}(k,t) \equiv S(k,t)/\rho_0 f(k,t)$$

  where ρ_0 *is initial slab density.*
    - -- *Perturbation must be linear for this to be valid*
    - -- *If nonlinear saturation occurs, resort to Haan model***
    - -- *Actual initial surface perturbation* $P_0(k,t)$ *must be minimized or subtracted*
    - -- $P_{eq}(k,t)$ *is not a unique attribute of a given microstructure, but depends on radiation drive history, drive spectrum, slab thickness, composition, etc.*

- **We will pursue basic theory and modeling at low level**

*B.A. Remington *et al, Phys. Rev. Lett.* **67**, 3259 (1991)
S.W. Haan, *Phys. Rev. A* **39, 5812 (1989)

First experiments at Omega: Radiography of Be/Cu slabs driven by "halfraum"

Diagnostic efforts include:

- **Hohlraum characterization**
  - *Experiments require long slowly rising drive to maximize growth factor*
  - *Diagnostics: Stepped slab, wedge witness plate, DANTE*
- **Side-on slab radiography**
  - *Slab trajectory, acceleration history*
  - *Verify drive history*
- **Face-on slab radiography**
  - *Time-varying spatial distribution of slab areal density* $\int \rho dz$

Experiment geometry and parameters:

- **12 to 15 Omega beams on P6-P7 axis**
  - *~190 eV drive is achievable*
  - *QXI, GXI, FXI gated imaging instruments are available*
- **Slabs**
  - *Type I: Smoothest possible surface, to emphasize volume microstructure*
  - *Type II: Intentional sinusoidal surface perturbation*
    - *-- Calibrate growth-factor calculations*

Initial computational modeling centers on designing slab/foil and radiation drive history for Omega experiments

- **Goal: choose drive history, slab thickness to give maximum perturbation growth on Omega laser**
  - *Modeling approach: calculate single-mode sinusoidal perturbation growth, for variety of candidate slab thicknesses, drive histories, and spectra*
  - *Use slowly rising pulse to keep slab on low adiabat, minimize preheat*
  - *Set initial shock pressure to maximize velocity anisotropy for ART seeding*
- **Major concern: Is Omega drive strong enough, and microstructure seed large enough, that microstructure-seeded perturbations become visible?**
  - *Line VISAR observations of free-surface velocity for shocked beryllium foils* give some information about magnitude of velocity fluctuations*
  - *Basic theory could give some guidance here, but needs development*
  - *Meanwhile, simply try to maximize growth factor spectrum with Omega drive*

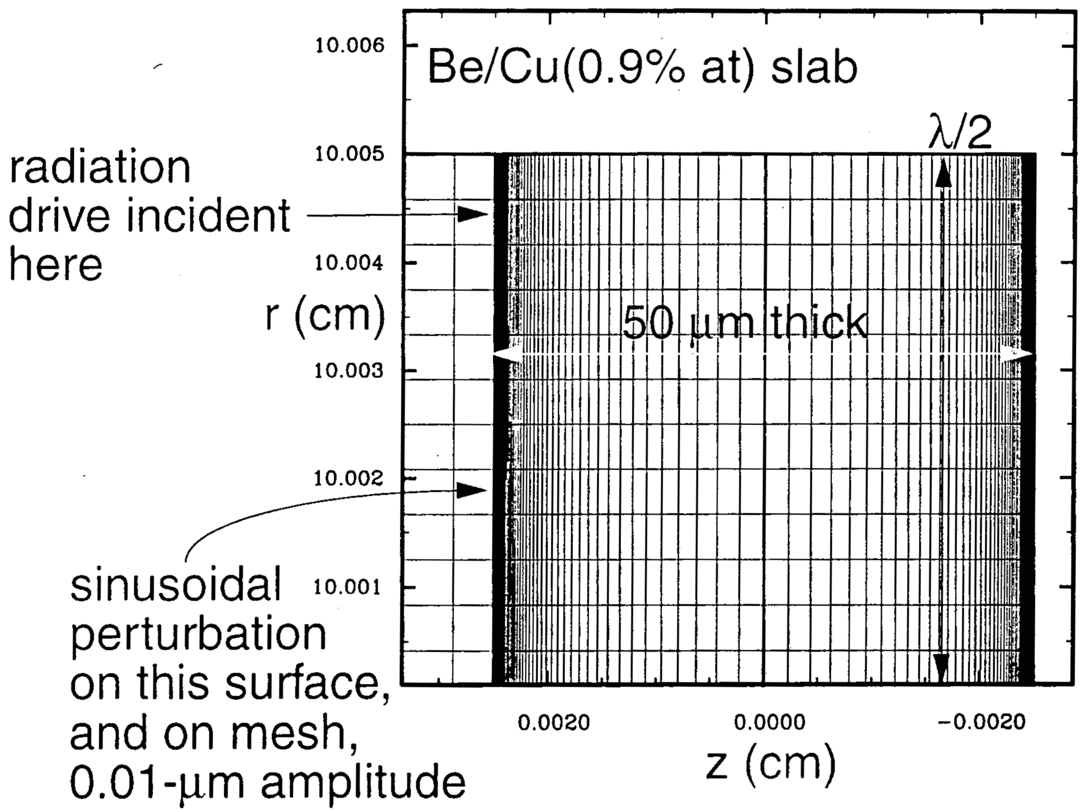
See poster by Tubbs et al. (this session) for hohlraum designs to produce desired drive histories

*D. Swift, LANL report LA-UR-01-6430, 15 November 2001.

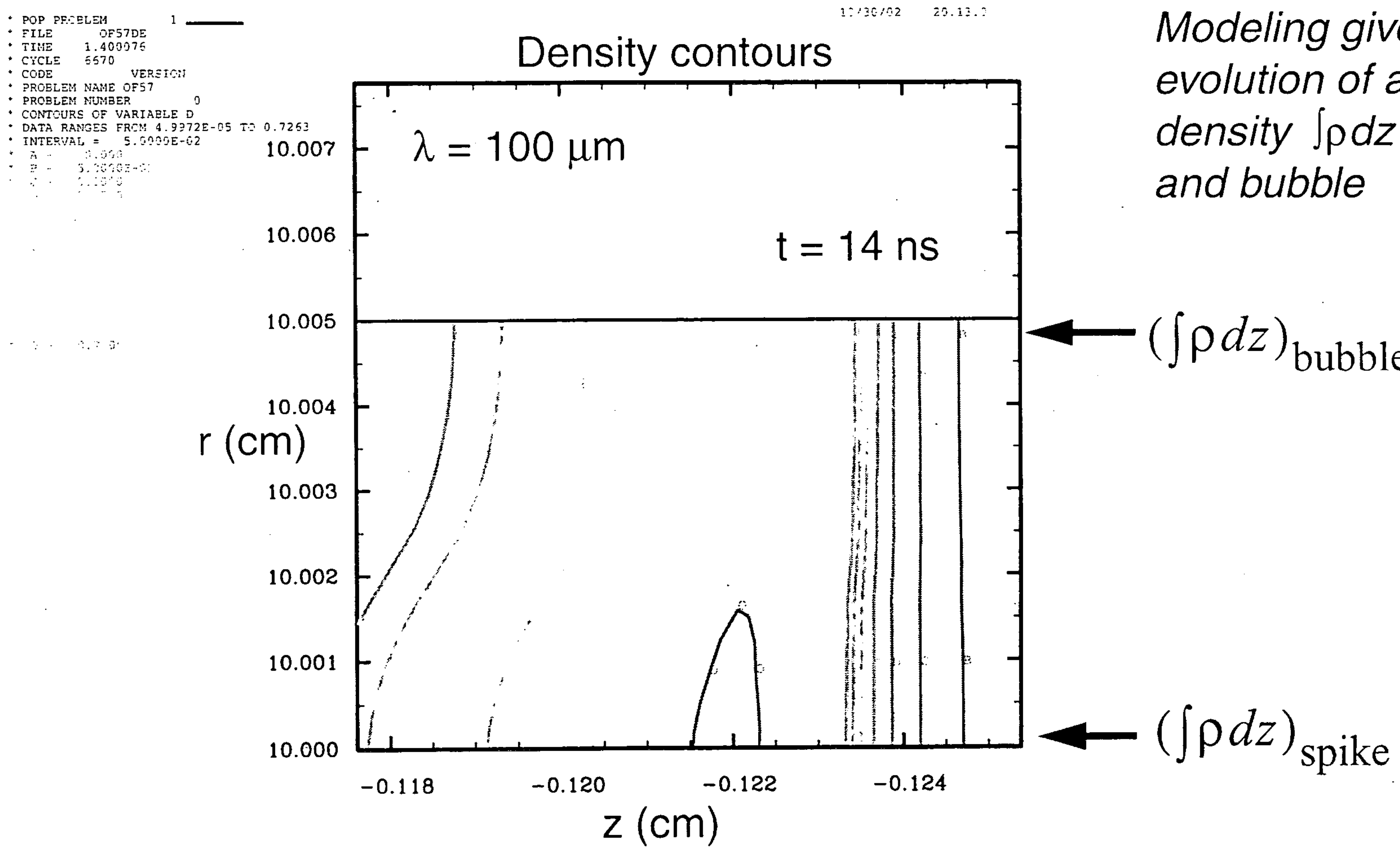
Linear stability modeling consists of calculating growth of single-mode sinusoidal surface perturbation

- **Although we model surface perturbation, not microstructural perturbation, we can obtain quantitative measure of slab stability: growth factor spectrum of perturbations**

Initial mesh for calculation with perturbation wavelength λ = 100 μm



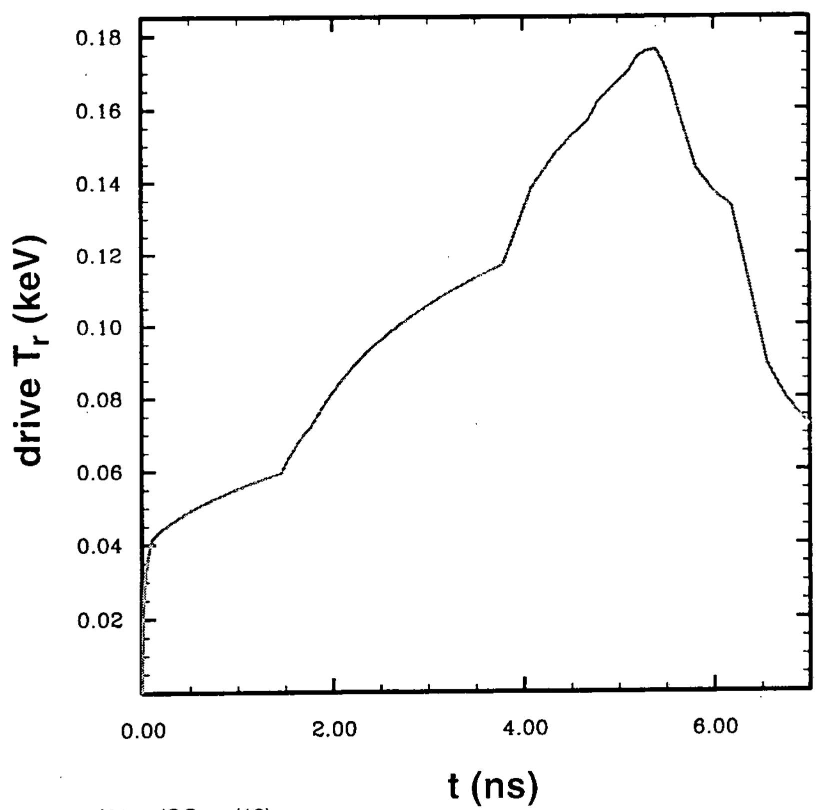
Linear stability modeling computes development of contrast between peak and valley for small-amplitude single-mode perturbation



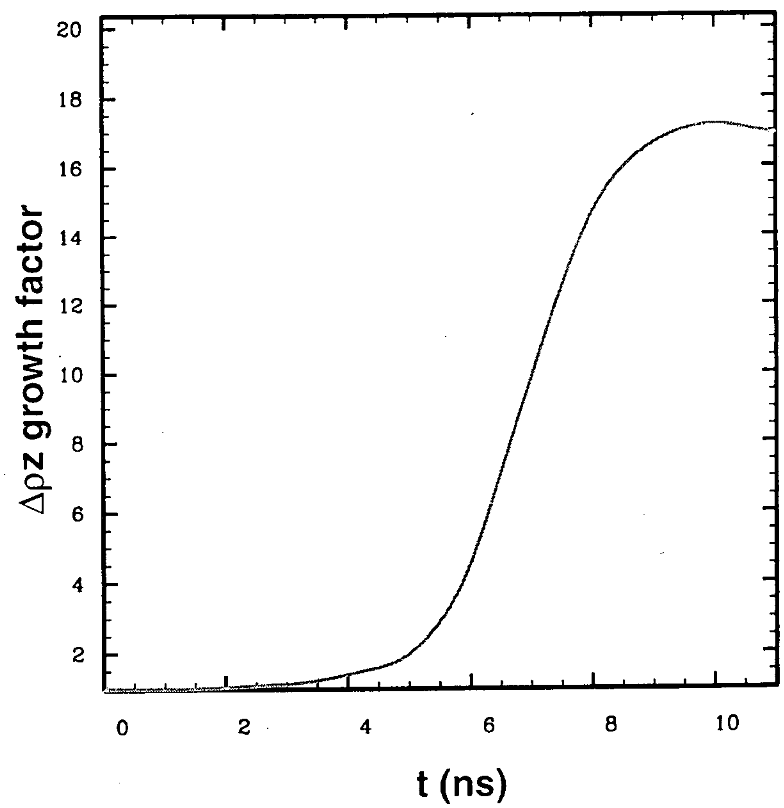
Modeling gives time evolution of areal density $\int \rho dz$ in spike and bubble

Trial Omega drive pulse with high-preheat drive spectra gives growth factor ~ 17 for λ = 100 μm and 50-μm foil.

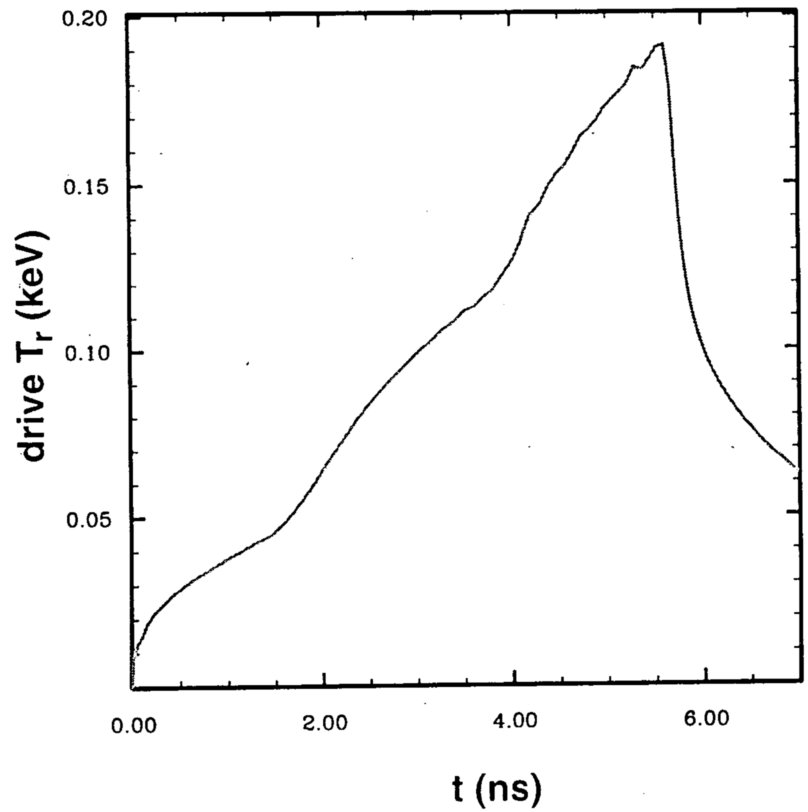
$\Delta\rho z$ *growth factor (t)* $\equiv [(\int\rho dz)_{spike} - (\int\rho dz)_{bubble}]_t / [(\int\rho dz)_{spike} - (\int\rho dz)_{bubble}]_{t=0}$

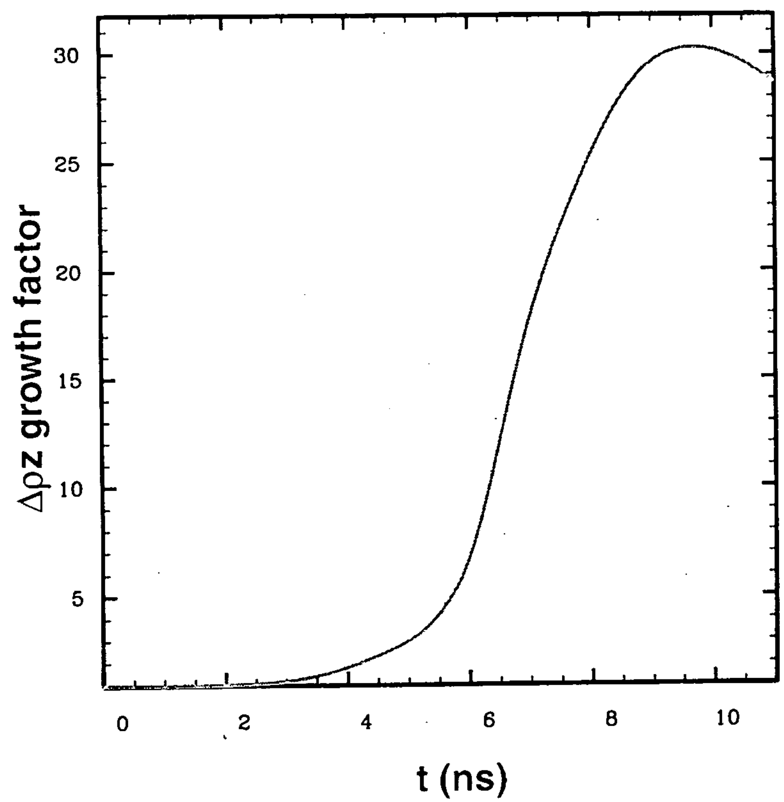


of54 (OOmod12)



Current proposed Omega drive pulse with realistic calculated spectra gives growth factor ~30 for λ = 100 μm and 50-μm foil.

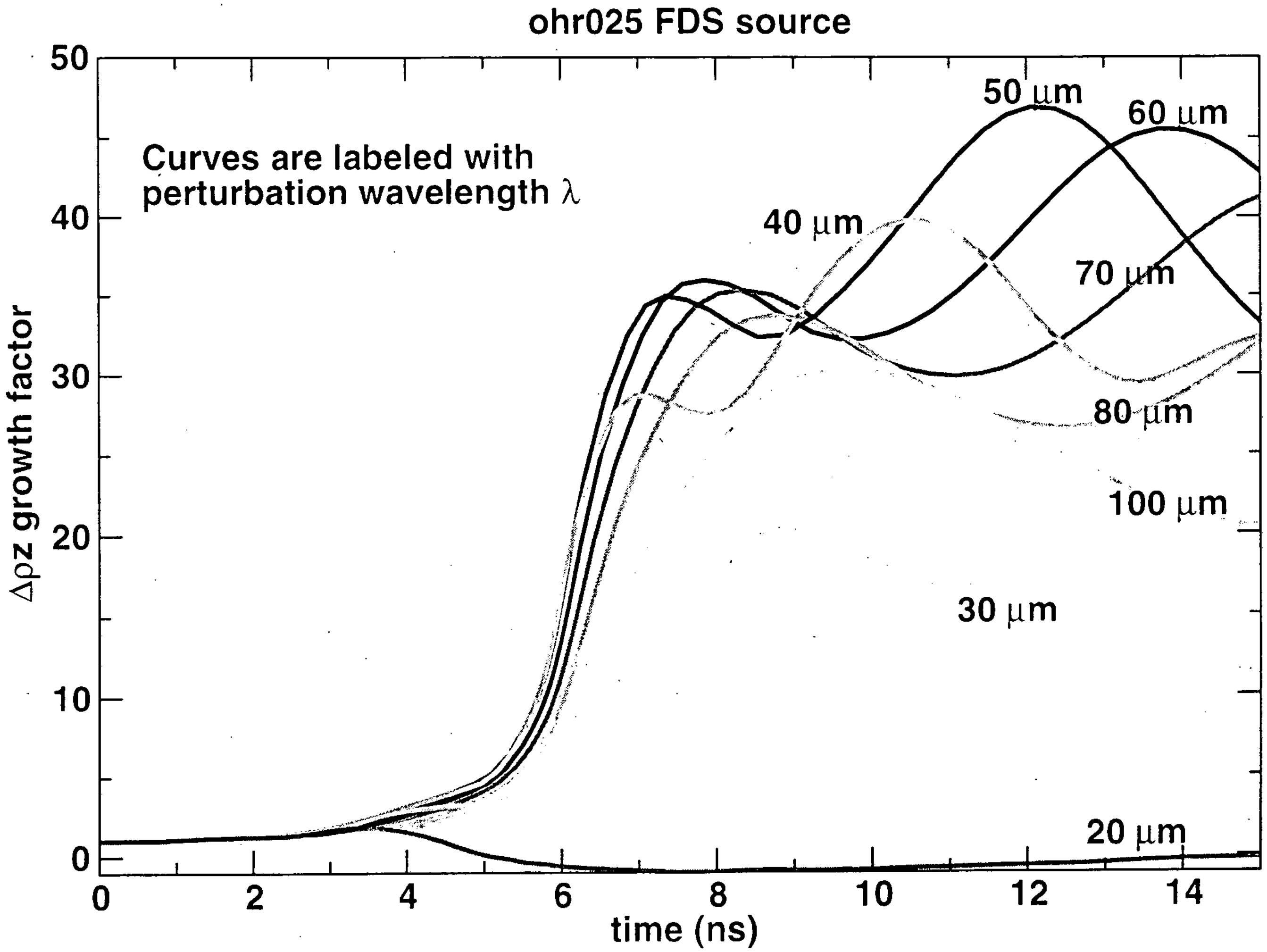




of58,59 (ohr025)

Calculations using current proposed Omega drive pulse with 50-μm foil show greatest growth factor occurs for λ = 50 μm.

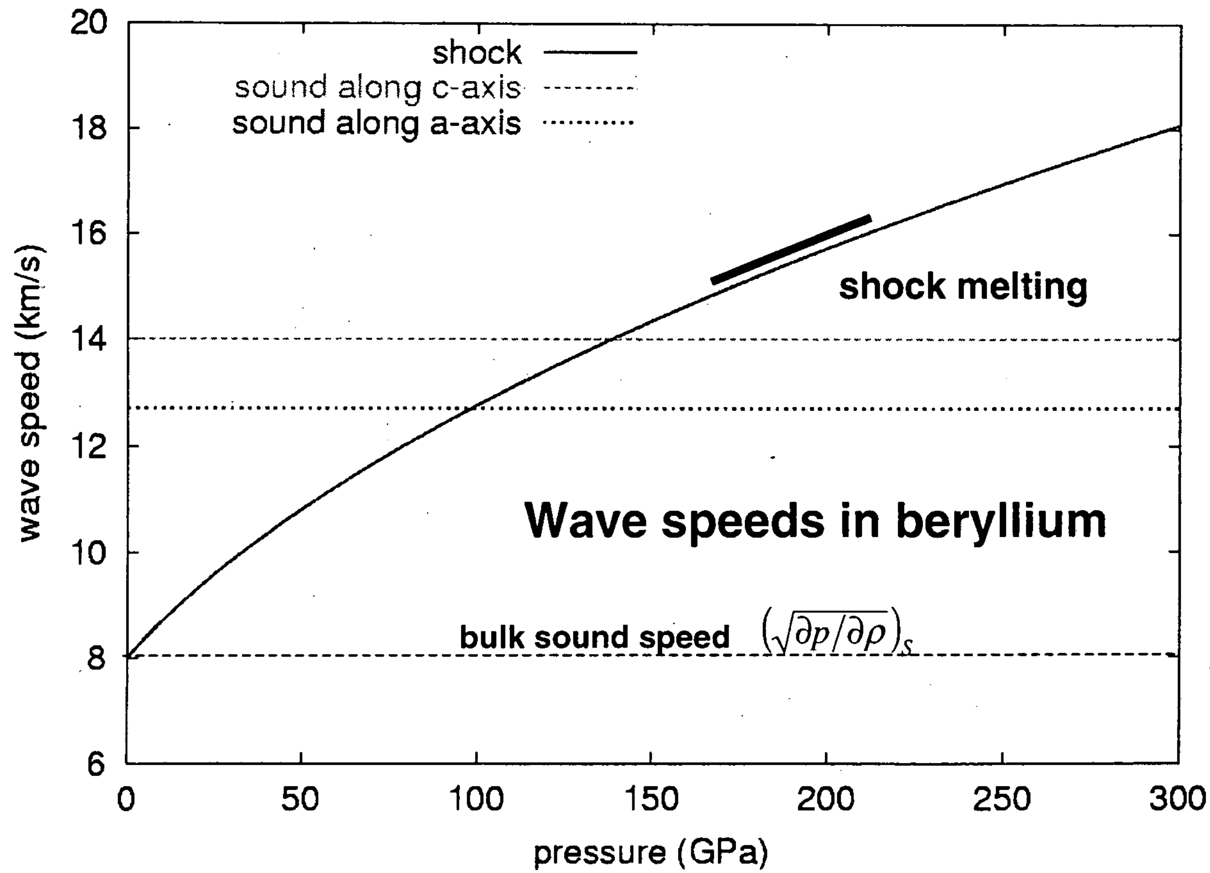
Time-dependent growth factors for 50-μm Be/Cu foil



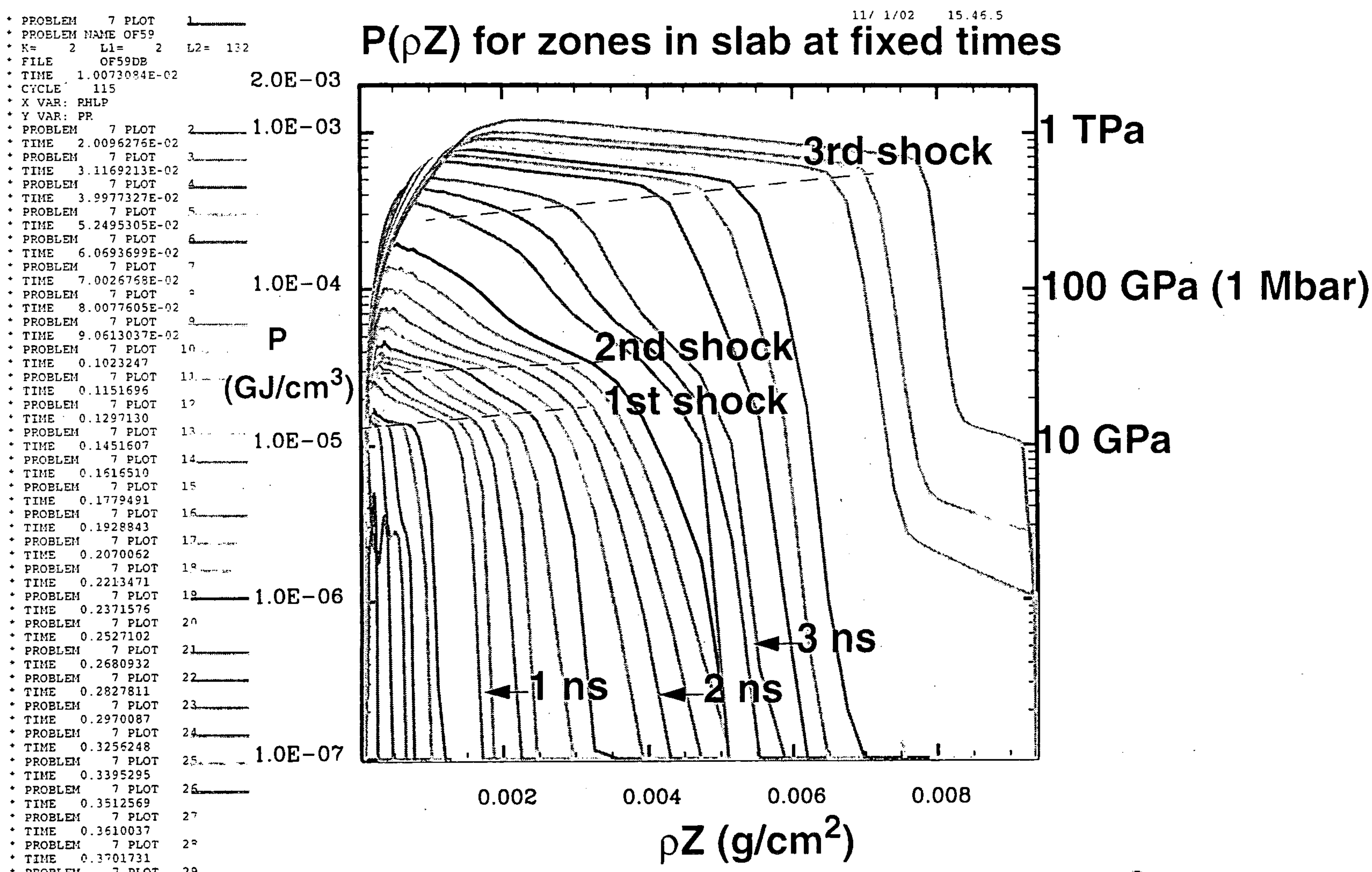
One goal of experiment is to test influence of shock strength on microstructure-seeded perturbations.

- NIF capsules are expected to have first shock pressure in the range 100 - 200 GPa (1 - 2 Mbar)
- Choice of NIF shock pressure is constrained by implosion design considerations: Need to keep shell on low adiabat
- But this is a dangerous range of pressure --- shock at 100 GPa will maximize microstructure-seeded velocity fluctuation
- So in initial Omega experiments we will test effect of shock pressure in seeding instability
- We will vary strength of initial shock from 100 GPa to 200 GPa, thus varying amplitude of seed, while keeping slab instability (growth factor) constant

Greatest velocity fluctuation is induced for ~100 GPa shock, where elastic precursor disappears on *a* axis, but not *c* axis.



Current proposed Omega drive pulse generates first and second shock in range 10 - 30 GPa in first 20 μm of slab.



Other sources of perturbation include engineering features associated with fabrication: fill tubes, plugs, joints, etc.

- **We plan to investigate effect of such "initally nonlinear" perturbations in Omega experiments**
  - *-- Specification for allowable fabrication features will be based on modeling and experiments*

- **Still other sources of perturbation are associated with microstructure, although not with crystal anisotropy**
  - *-- Oxygen contaminant may accumulate at grain boundaries*
  - *-- Copper dopant may be distributed nonuniformly*

Future work:

- Design second pulse shape, giving first shock strong enough to melt Be/Cu grains
- Ensure that pulse shapes can actually be produced at Omega
- Make theoretical predictions of magnitude of velocity fluctuations in Be or Be/Cu that seed ART instability
- Choose concentration of copper dopant